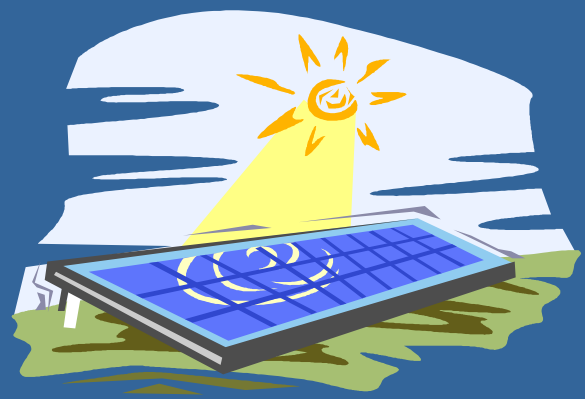
Solar Photovoltaic Systems

Standards for Permitting, Installation, Code Compliance and Inspections

John Hoffner, CSG

DER Road Show



A little bit about Me

- **Worked for Austin Energy 14 years**

SUN POWER ELECTRIC
Clean power. . . generation to generation

- **Designed many solar electric Systems. Helped write IEEE Standard for interconnection**

- **Manager for Renewables for CSG**

A little bit about CSG

- **We are an Energy Services Company**

- **We operate a Non-profit Solar Utility called Sun Power**

- **We design and install commercial scale PV systems**

Three Important Things

1. What is Solar Electricity

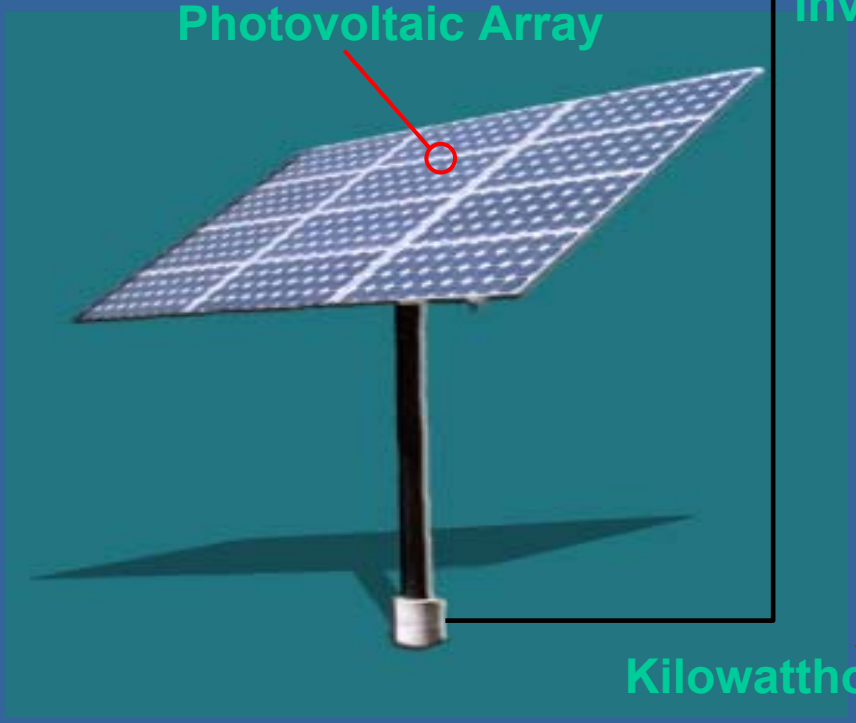
2. What you need to know

   to Connect with the Local Electric Utility

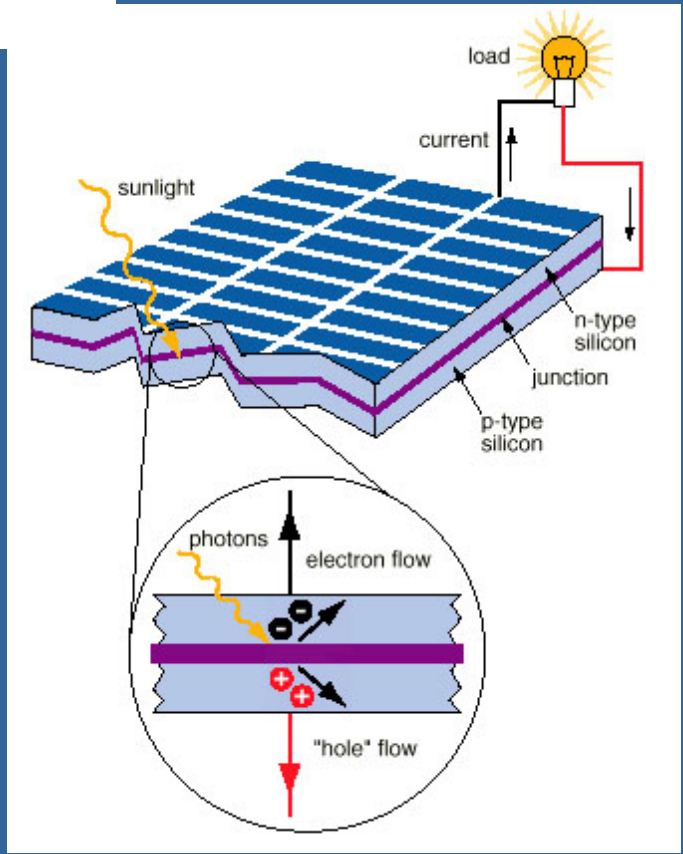
3. Solar Electricity in Texas

   (Bonus – Other Resources)

1. What is Solar Electricity



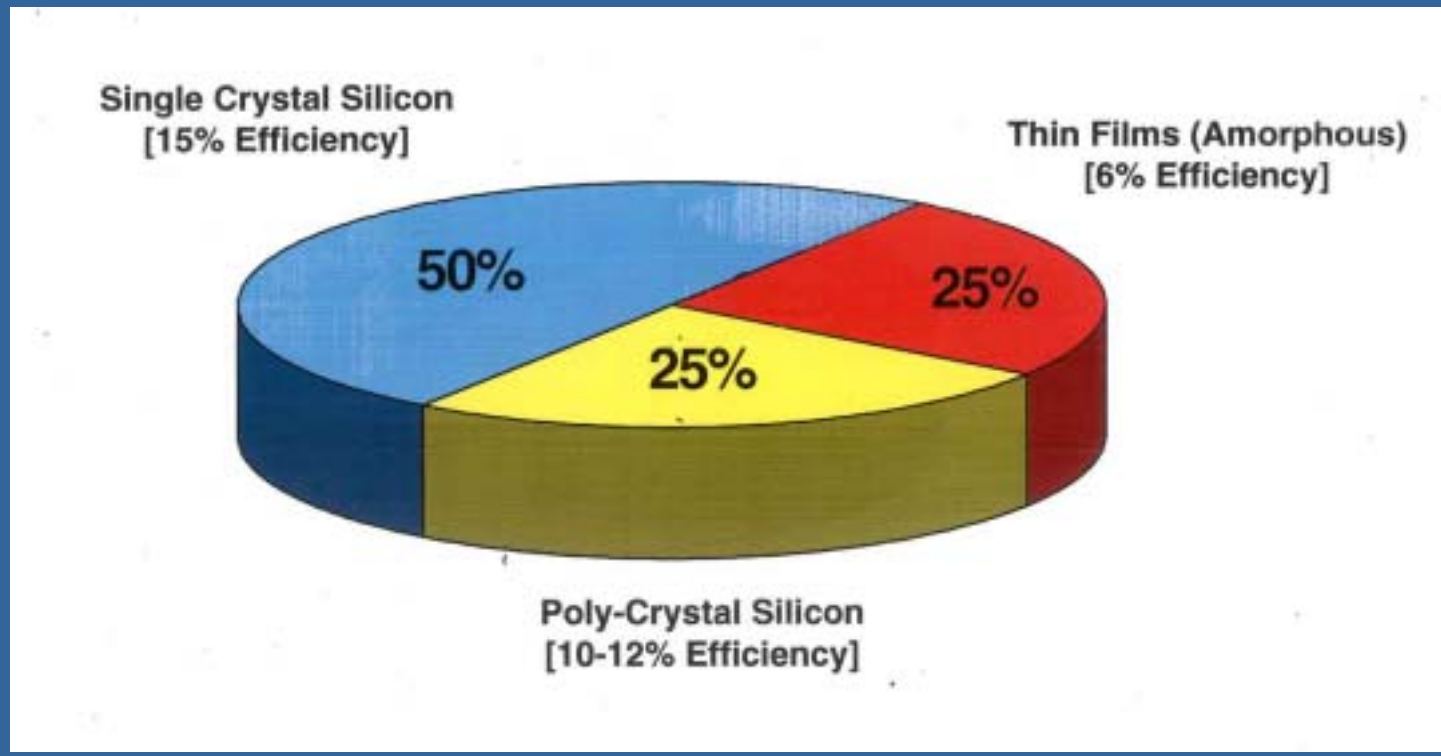
How Solar Cells Work



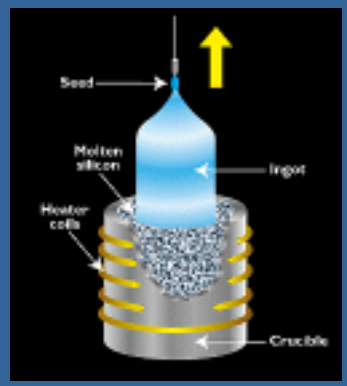
Commercial Solar Cells

- Single-Crystal Silicon
- Poly-Crystal Silicon
- Thin-films

Cell Market

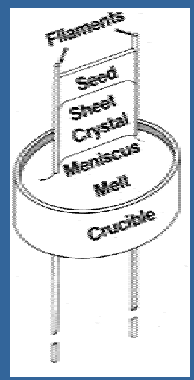

Single Crystal Silicon
[15% Efficiency]
Thin Films (Amorphous)
[6% Efficiency]
50%
25%
25%
Poly-Crystal Silicon
[10-12% Efficiency]

How cells are made



Other types of cells

- Poly-crystal
- Thin-film
- Ribbon type



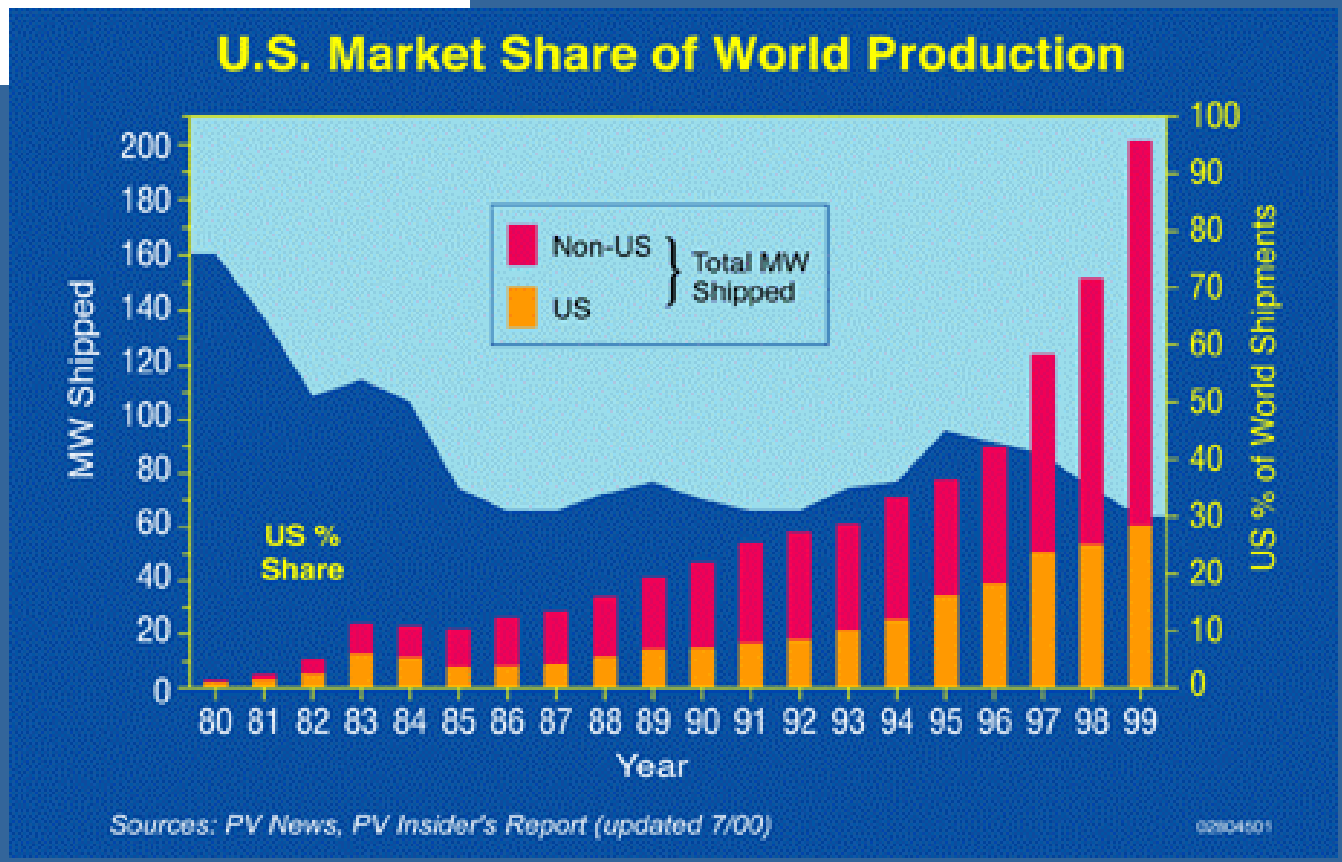
Some of the Manufacturers

- Shell (previously Siemens) Solar
- ASE Americas
- BP Solar
- Astropower
- Kyocera
- Evergreen Solar

Emerging Technologies

- DuPont - Electrically Conductive Plastics
- ASE – Modules with reflectors
- Siemens - Copper Indium Diselenide
- Evergreen Solar - New type of ribbon
- High Efficiency Space Cells - Gallium Arsenide
- BP Solar - Cadmium Telluride

Solar Cell Shipments



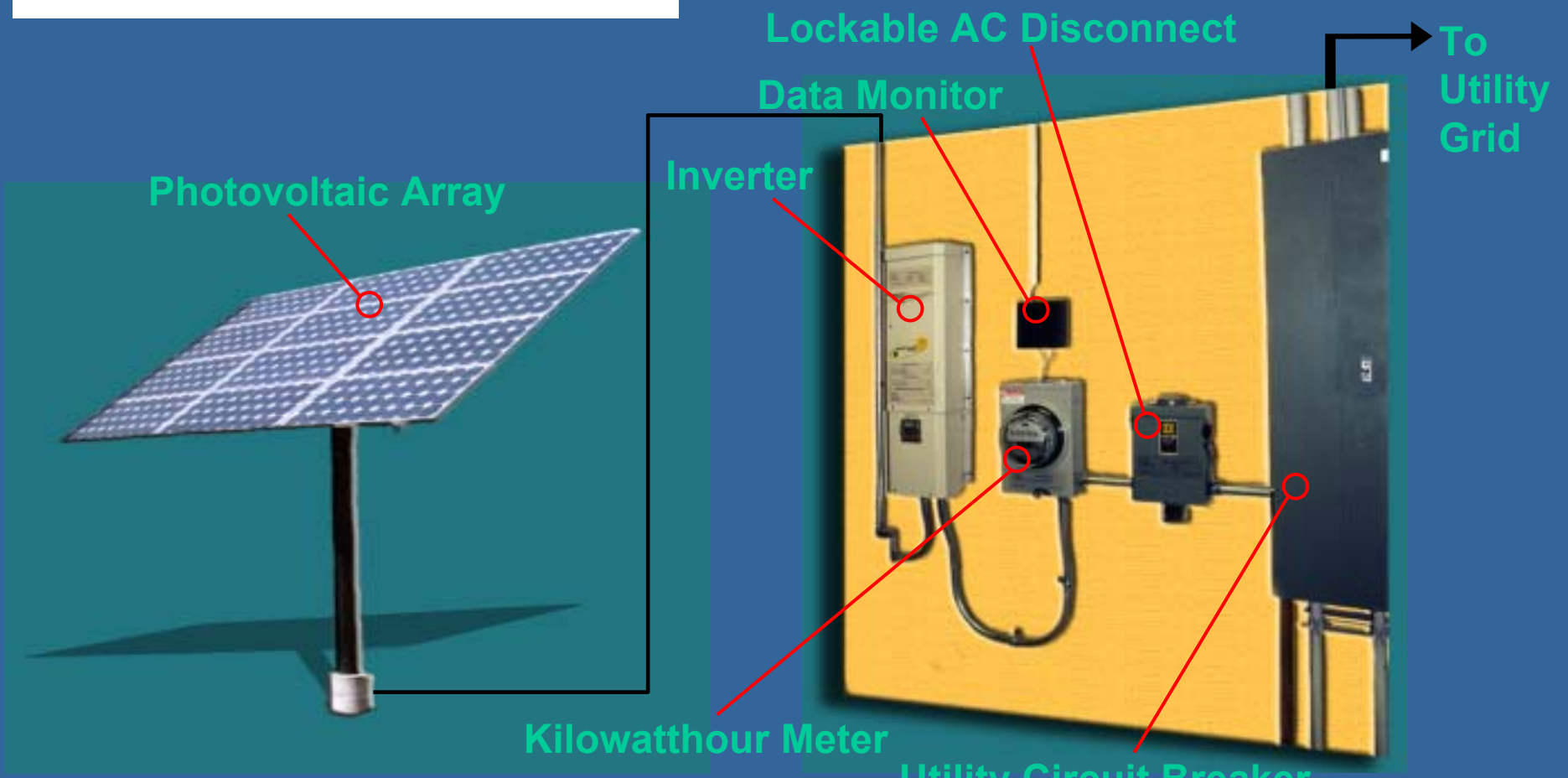
Photovoltaic Arrays

- **Array (690.2)**
  - A mechanical integrated assembly of modules or panels with a support structure and foundation, tracker, and other components, as required, to form a direct-current power-producing unit.

Solar Cell Summary

- Cells continue to improve in efficiency
- Manufacturing continues to improve
- Use commercially available today's systems
- Most common use silicon cells

Balance of System Parts



Balance of System

- Inverter
- Metering/monitoring
- Lockable disconnect
- Breaker panel

Inverters

- Convert DC to AC electricity
- Conversion is 80 to 95 % efficiency
- Utility-tied
- Use inverters that are UL approved

2. What you need to know to Connect with the Local Electric Utility

- Interconnection standards and codes
  - IEEE Standards
  - State Standards and Codes
  - Local Utility requirement
- Use UL listed equipment

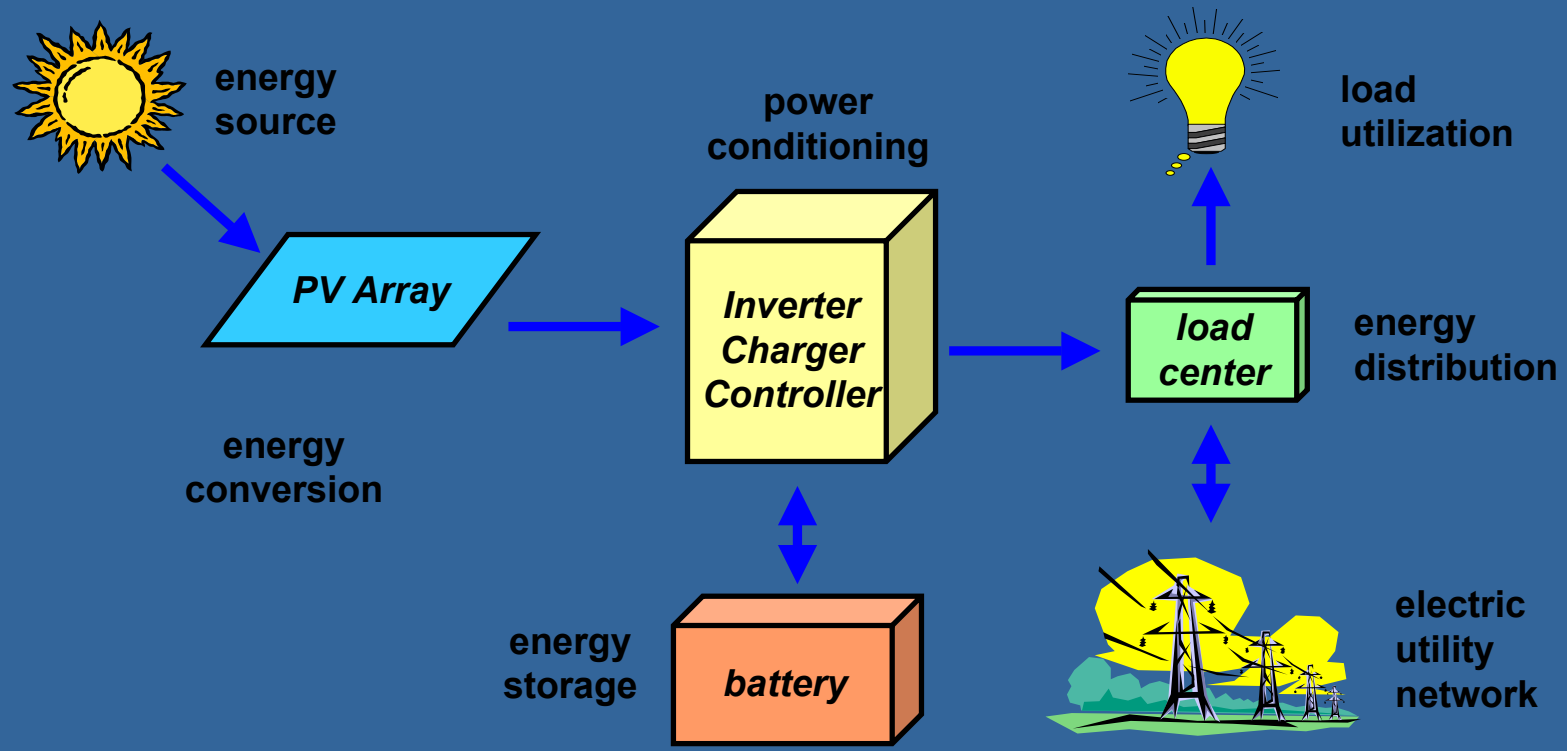
Requirements for Solar Photovoltaic System Installations

- **Permits**
  - Building permits are applied for by contractor or property owner.
  - Plans examiner reviews plans, grants approvals as required.
- **Installation**
  - System is installed by a licensed contractor (or property owner) in a code-compliant manner, in accordance with jurisdictional requirements.
- **Inspections**
  - Installation is inspected by the local building code official and approved.
- **Interconnection**
  - Owner completes interconnection agreement with local utility, including requirements for system design and equipment, inspection certificates, insurance, disconnect provisions and other matters as required.

Example: Who Installs and Inspects PV Systems in Florida

- **Solar Contractor**
  - FS 489 Part I, FAC 61G4
  - Construction Industry Licensing Board:
  - http://www.state.fl.us/dbpr/pro/cilb/cilb_index.shtml
- **Electrical Contractor**
  - FS 489 Part II, FAC 61G6
  - Electrical Contractors' Licensing Board: http://www.state.fl.us/dbpr/pro/elboard/elec_index.shtml
- **General Contractors and others**
  - see restrictions in FS 489 Part I, FAC61G4
- **Property owner**
  - see exemptions and restrictions, FS 489 Part I and Part II
- **Building Code Administrators and Inspectors**
  - FS 468 Part XII, FAC 61G19
  - Building Code Administrators and Inspectors Board:
  - http://www.state.fl.us/dbpr/pro/buildc/bc_index.shtml

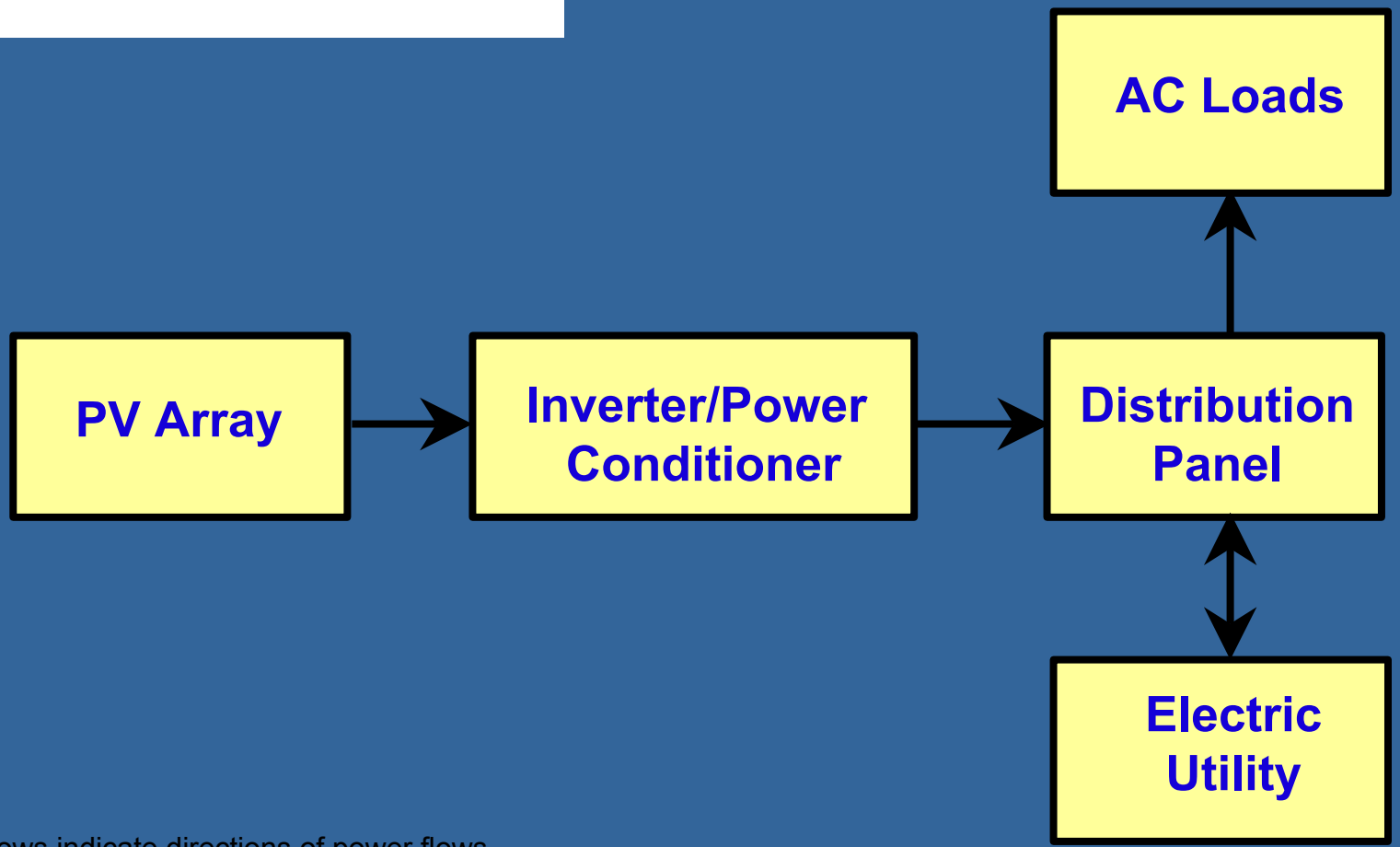
Solar Photovoltaic System: Advance Organizer



Types of Interactive Solar Photovoltaic Systems

- **Simple Utility-Interactive**
  - PV system supplements on-site energy usage, electrical loads are supplied by either the PV system or utility or a combination of both, depending on the amount of PV generation and magnitude of the load.
  - PV array is directly connected to the inverter input, and inverter AC output is connected to the utility grid.
  - PV system operates in parallel and synchronously with the utility grid.
- **Utility Interactive with Battery Storage**
  - Can operate either in interactive or stand-alone mode, but not simultaneously.
  - PV, inverter and battery subsystems interface between the customer's main service panel and dedicated load subpanel.
  - In interconnected mode, excess PV energy not required for battery charging is inverted and supplements on-site loads or is sent back to utility.
  - When the grid de-energizes, inverter isolates from grid and powers load subpanel directly from batteries, similar to a UPS system.
  - Bypass switch allows load subpanel to be directly powered from grid, isolating the SPS.

Simple Utility-Interactive PV System (no energy storage)



* Arrows indicate directions of power flows

Utility-Interactive PV System with Battery Storage

* Arrows indicate directions of power flows

Inverters for PV Systems

- **Inverter (690.2)**
  - Equipment that is used to change voltage level or waveform, or both, of electrical energy. Also known as a power processing unit (PCU) or power conversion system (PCS), and inverter is a device that changes dc input to ac output. Inverters may also function as battery chargers that use alternating current from another course and convert it into direct current for charging batteries.
  - Inverters for PV systems in sizes from 100 watts to custom designs of up to 1 MW or more
  - DC operating voltages of 12 volts up to 600 volts, with AC outputs from 120 V single phase to 480 V three phase.

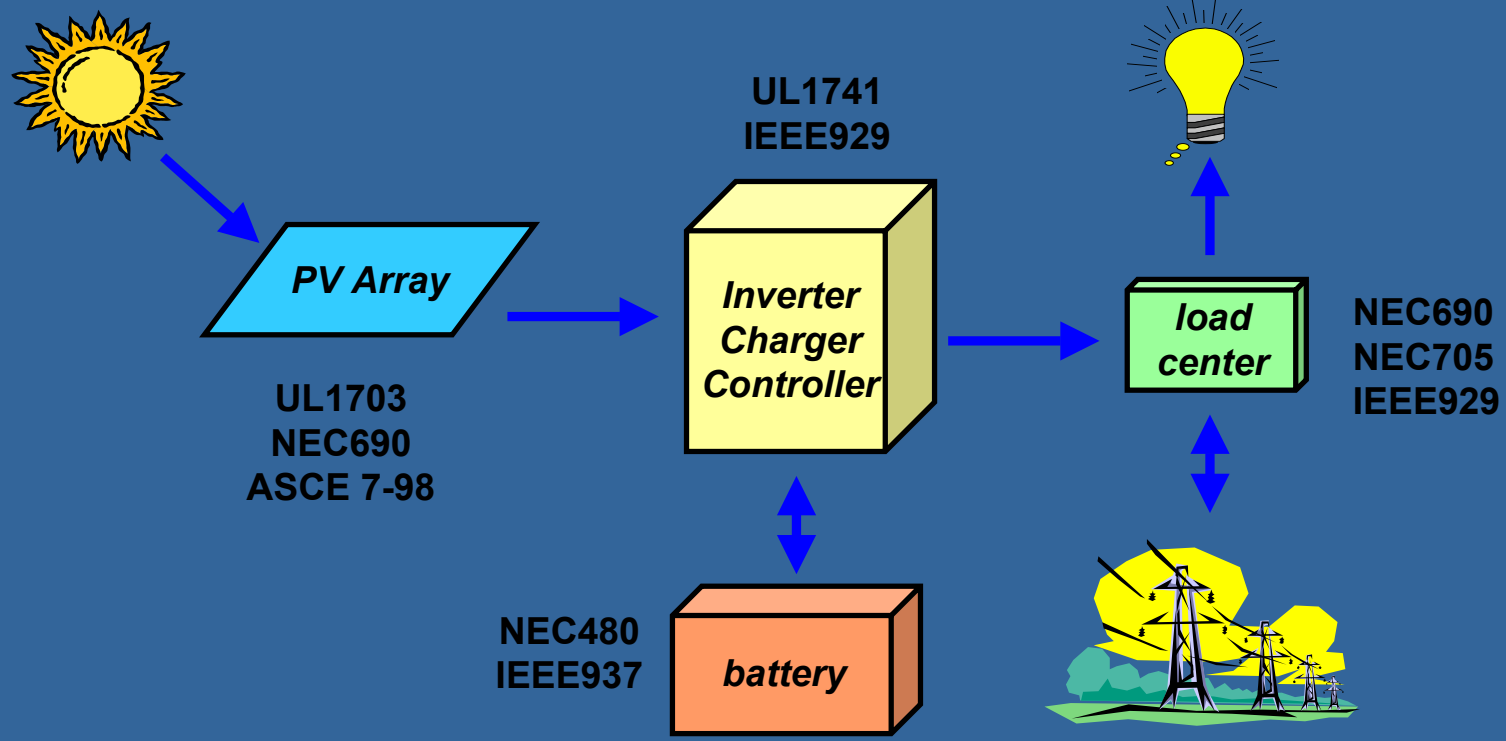
Batteries for PV Systems

- Batteries are used in some PV systems to *store energy* produced by the PV array and supply it to electrical loads as needed.
- Charge control is required in most cased to protect batteries from overcharge by PV array, and overdischarge from loads.

Principal Standards for Solar Photovoltaic Systems and Equipment

- **IEEE 929-2000 Recommended Practice for Utility Interface of Photovoltaic (PV) Systems**
  - IEEE P1547 Draft Standard for Distributed Resources Interconnected with Electric Power Systems (will apply to a broad range of interconnected distributed generation equipment)
- **UL Standard 1741 – Inverters, Converters, and Controllers for Use in Independent Power Systems**
  - Includes requirements of IEEE 929-2000
- **UL Standard 1703 – Flat-Plate Photovoltaic Modules and Panels**
- **National Electrical Code™**
  - Article 690 Solar Photovoltaic Systems
  - Article 705 Interconnected Electric Power Production Sources
  - Requires inverter UL1741 listing identified for interactive operation
- **Local and state building codes**

Solar Photovoltaic System: Applicable Codes by Component



PV Systems and the National Electrical Code©

- **Article 690** addresses safety standards for the installation of PV systems.
- Many other articles may also apply to PV installations:
  - Article 110: Requirements for Electrical Installations
  - Article 230: Disconnect Means
  - Article 240: Overcurrent Protection
  - Article 250: Grounding
  - Article 300: Wiring Methods
  - Article 480: Storage Batteries
  - Article 685: Integrated Electrical Systems
  - Article 705: Interconnected Electric Power Production Sources
  - Article 720: Circuits and Equipment Operating at Less than 50 Volts

Electrical Code Compliance and Equipment Listing

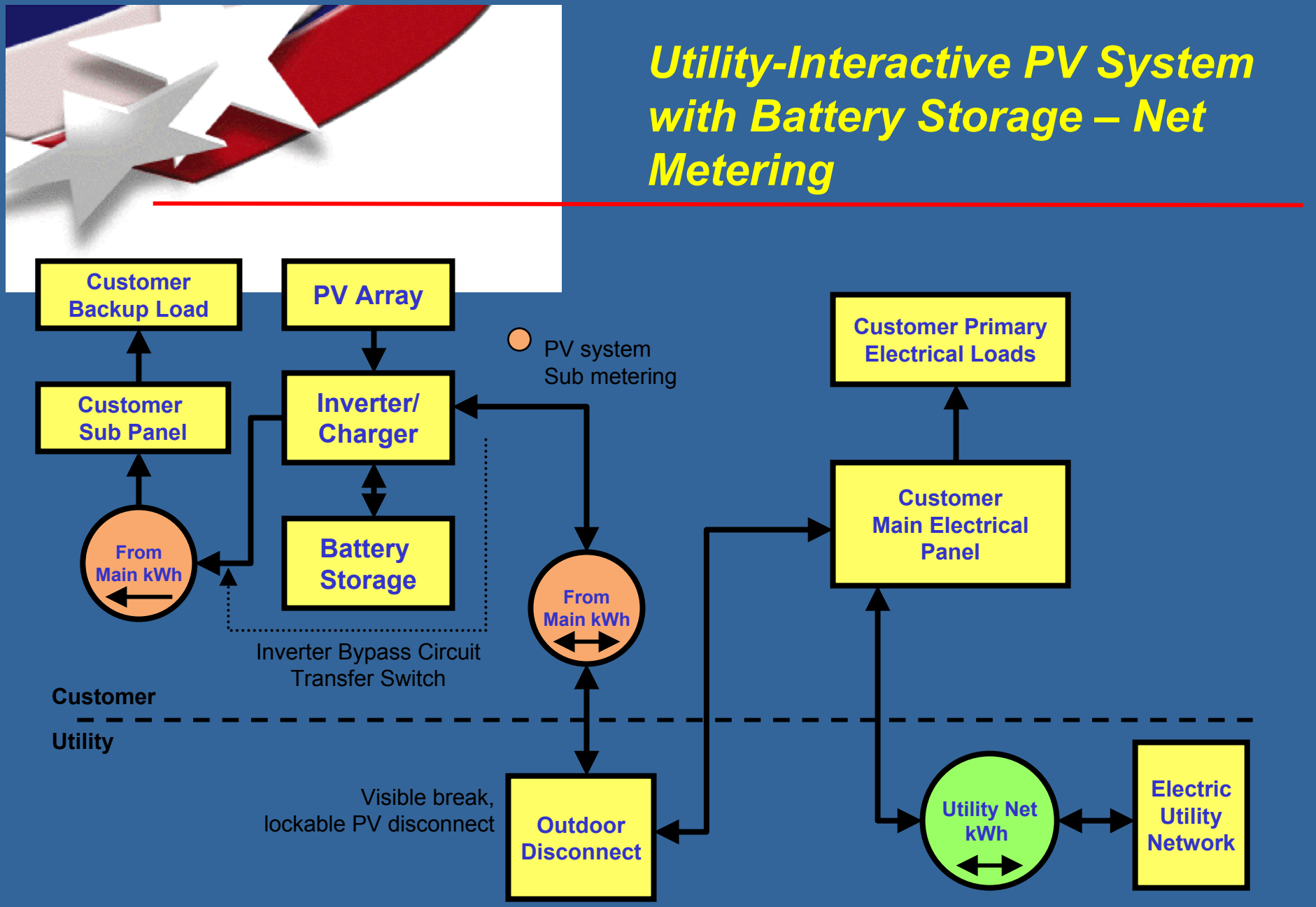
- NEC requires approvals or listing for components and electrical hardware. Recognized laboratories include:
  - Underwriters Laboratory (UL) http://ulstandardsinfonet.ul.com
  - ETL Semko http://www.etlsemko.com
  - Canadian Standards Association (CSA) http://www.csa.ca
  - FM Global http://www.fmglobal.com
- Article 110-3(B): Examination, Identification, Installation, & Use of Equipment.
  - **(B) Installation & Use**. Listed or labeled equipment shall be used or installed in accordance with any instructions included in the listing or labeling.

Utility Interconnection: Typical Issues

- Listed equipment
- Inspected and approved installations
- Liability insurance
- Disconnect provisions
- Metering options
- Billing practices
- Testing and monitoring
- Size restrictions
- Fees for interconnection application, special billing or metering

Utility-Interactive PV System No Battery Storage – Net Metering

Utility-Interactive PV System with Battery Storage – Net Metering



Elements of a Quality and Code-Compliant PV System Installation

- System employs a well-engineered design and quality components;
- System and equipment are properly sized to meet expected or required performance;
- System uses listed, approved and appropriately rated equipment, and sunlight and weather resistant materials for outdoor application;
- PV array is mounted in an accessible, unshaded location with proper solar orientation, and uses roof penetrations and weather sealing methods consistent with accepted roofing industry standards;
- All equipment is properly labeled and safety hazards identified;
- Installation complies with all applicable building and electrical codes and accepted utility interconnection practice;
- System is inspected and approved by utility and code officials, owners/operators are trained on safety and operation.

PV System Code Compliance: Common Problem Areas

- Insecure structural attachment of PV arrays to rooftops and other structures (e.g., attachment of roof mounts directly to roof decking)
- Inadequate weather sealing for roof penetrations
- Unsafe wiring methods, insufficient conductor ampacity and insulation type
- Lack of or improper placement or ratings of overcurrent protection and disconnect devices
- Unsafe installation, improper use and maintenance for batteries
- Use of unlisted equipment or improper application of listed equipment
- Lack of or improper system grounding
- Lack of or inadequate labeling on major system components and disconnect devices
- Lack of or inadequate documentation on system design, and operating and maintenance requirements

Photovoltaic System Installation: Inspection Checklist

- Photovoltaic source and output circuit conductors shall not be run with other conductors **[690.4(B)]**
- Equipment shall be identified for use in solar photovoltaic systems **[690.4(D)]**
- DC ground fault protection shall be provided for PV arrays on dwellings **[690.5]**
- Alternating-current modules shall have appropriate markings, overcurrent protection, disconnect means and GF protection **[690.6, 690.52]**

Circuit Requirements for PV Systems: Inspection Checklist

- Maximum system voltage at lowest temperature shall be less than module maximum voltage rating (most modules listed for 600 volts) **[690.7]**
- Maximum system voltage shall be less than 600 volts for dwellings, over 150 volts accessible only to qualified persons **[690.7(C)(D)]**
- Module conductors should be rated for at least 90^{o} C **[690.8(A)]**
- Photovoltaic source and output circuit conductors and overcurrent protection devices shall be sized for no less than Isc x 1.25 x 1.25 **[690.8(B)]**
- Inverter output circuit conductors and overcurrent devices shall be sized for the inverter continuous output current rating **[690.8(A)(3)**
- Stand-alone inverter input circuit conductors and overcurrent devices shall be sized for input current at rated output at lowest operating voltage x 1.25 **[690.8(A)(4)]**
- Equipment and devices rated for 125% of maximum voltage

Overcurrent Protection for PV Systems: Inspection Checklist

- Photovoltaic source circuit, photovoltaic output circuit, inverter output circuit and storage battery circuit conductors and equipment shall be protected in accordance with Art. 240 **[690.9(A)]**
- Overcurrent protection shall be provided for power transformers in accordance with Art. 450.3 **[690.9(B)]**
- Branch-circuit or supplementary-type overcurrent devices shall be provided for photovoltaic source circuits, no greater than series fuse on module listing **[690.9(C)]**
- Overcurrent devices are listed for use in dc circuits and shall have the appropriate voltage, current and interrupt ratings **[690.9(D)]**
- No issues with multiwire branch circuits **[690.10(C)]**

Disconnect Means for PV Systems: Inspection Checklist

- Disconnect means shall be provided between photovoltaic power system output and other building conductors, no disconnect in grounded conductor. **[690.13(A)]**
- Photovoltaic disconnecting means shall be installed at a readily accessible location either outside of a building or structure or inside nearest the point of entrance of the system conductors (not in bathrooms) **[690.14(C)]**
- Each photovoltaic system disconnect means shall be marked, suitable for use, no more than six grouped disconnects for PV system **[690.14(C)]**
- Disconnect means shall be provided for inverters, batteries, charge controllers, and the like, from all ungrounded conductors of all sources **[690.15]**

Disconnect Means for PV Systems: Inspection Checklist (cont.)

- Disconnecting means shall be provided to independently disconnect a fuse from all sources of supply if the fuse is energized from both directions **[690.16]**
- Switches or circuit breakers shall be provided to disconnect ungrounded conductors, are readily accessible, have on/off indication, and have appropriate interrupt rating **[690.17]**
- Energized disconnects in open position shall be labeled as such **[690.17]**

PV System Wiring Methods: Inspection Checklist

- Appropriate wiring methods shall be used **[690.31(A)]**
- Single conductor cables type SE, UF, USE, and USE-2 single-conductor are permitted in photovoltaic source circuits, sunlight resistant cable shall be used **[690.31(B)]**
- Flexible cords and cables, identified for hard service, outdoor and sunlight resistant are permitted for tracking or movable array mounts **[690.31(C)]**
- Single-conductor cables in sizes 16 AWG and 18 AWG shall be permitted for module interconnections where such cables meet the ampacity requirements of 690.8 **[690.31(D)]**
- Connectors permitted in Art. 690 shall be polarized, noninterchangeable, guarded, locking, and have first to make and the last to break contact for grounded conductor **[690.33]**
- Junction boxes **[690.34, 300-15, 370]**
- Conductors in systems operation 50 volts or less shall not be smaller than 12 AWG copper or equivalent **[720.4]**

Grounding in PV Systems: Inspection Checklist

- DC conductor shall be grounded at a single point for *two-wire* PV systems operating above 50 volts, center tap shall be grounded for bi-polar arrays. Disconnect switches shall not open-circuit the grounded conductor any time **[690.41]**
- DC grounding shall be made at any point on photovoltaic output circuit **[690.42]**
- Non-current-carrying metal components shall be grounded for all PV systems, including module frames, conduit and boxes as applicable **[690.43]**
- Equipment grounding conductor shall be sized for 125% of photovoltaic source and output circuit Isc. **[690.45]**
- Where GFID is used per 690.5, equipment grounding conductor shall be sized according to **[250.122]**
- Grounding electrode system shall be installed **[690.47, Art. 250]**

Solar Photovoltaic System Markings: Inspection Checklist

- Photovoltaic modules shall be labeled with UL, series fuse requirement, Voc, Vop, Vmax, Isc, Iop, Pmax **[690.51]**
- Photovoltaic power source shall be labeled with Iop, Vop, Vmax, Isc at disconnect **[690.53]**
- Point of interconnection shall be labeled with Volts AC, max amps AC at disconnect **[690.54]**
- Energy storage (batteries) shall be labeled with Vop max, Veq, polarity **[690.55]**
- Accessible notice and location of disconnect means shall be provided for stand-alone systems **[690.56]**
- Utility systems shall have location label if PV and service disconnect are not together **[690.56]**

Connection to Other Sources: Inspection Checklist

- Inverters shall be listed and identified for interactive operation **[690.60]**
- Interactive inverters shall de-energize when interactive source of power is lost **[690.61]**
- No unbalanced interconnections **[690.63]**
- Disconnect and overcurrent device for supply side interconnections **[690.64(A)]**
- Load side interconnections **[690.64(B)]**
  - Shall be made at dedicated branch circuit or fusible disconnect
  - Ampere rating of breakers feeding panel shall not exceed busbar rating (120% of busbar rating for dwellings)
  - Interconnection shall be on line side of any ground-fault protection equipment
  - Overcurrent devices supplying power to busbar shall be marked to indicate the presence of all sources of supply
  - Backfed breakers shall be identified

Batteries in PV Systems: Inspection Checklist

- Installation shall use appropriate racks, trays and ventilation **[480.8, 480.9, 480.10]**
- Operating voltage for dwelling less than 50 volts nominal - no more that 24 – 2-volt lead-acid cells in series **[690.71(B)]**
- Battery terminals and other live parts shall be guarded, adequate working space **[480.99(B),(C)]**
- Current-limiting fuses (types RK-5, RK-1, T) shall be installed on battery output circuits **[690.71(C)]**
- No conductive cases for batteries greater that 48 volts, nominal. Conductive racks permissible, must be at least 6” from top of battery case. **[690.71(D)]**
- Series disconnects shall be provided for battery strings over 48 volts, nominal **[690.71(E)]**
- Disconnect shall be provided for grounded conductor for battery systems over 48 volts, accessible only to qualified persons **[690.71(F)]**

Battery Charge Controllers: Inspection Checklist

- Battery charge control shall be used in any system where the charge rates are greater than 3% of battery capacity. Adjustment only accessible to qualified persons **[690.72(A)]**
- Systems using diversion charge controllers shall have secondary independent means for charge control. DC diversion loads, conductors and overcurrent devices must be rated for at least 150% of the controller current rating **[690.72(B)]**
- Temperature compensation probes attached to batteries?

Reference Resources

- Complete on-line resource for presentations, documents, reference and resource links:
  - http://www.fsec.ucf.edu/PVT/Education/training/inspgcps/handbook/index.htm
- Code and Standards for Photovoltaic Systems and Equipment:
  - http://www.fsec.ucf.edu/PVT/RESOURCES/pvcodes/index.htp
- Institute of Electrical and Electronics Engineers (IEEE) standards:
  - http://standards.ieee.org/
- Underwriters Laboratory standards:
  - http://ulstandardsinfonet.ul.com/
- National Electrical Code, NFPA 70, National Fire Protection Association:
  - http://www.nfpa.org

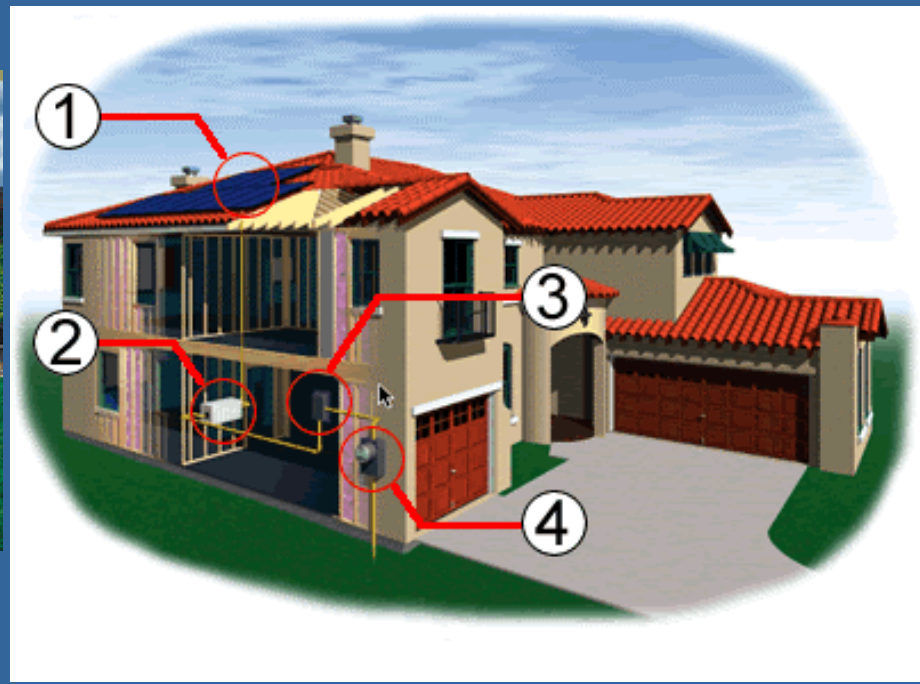
References (cont.)

- **Connecting to the Grid – Interstate Renewable Energy Association website:**
  - http://www.irecusa.org/connect/index.html
- **Florida Building Code**
  - http://www.floridabuilding.org/
- **ASCE 7-98 Minimum Design Loads for Buildings and Other Structures**
  - http://www.asce.org/

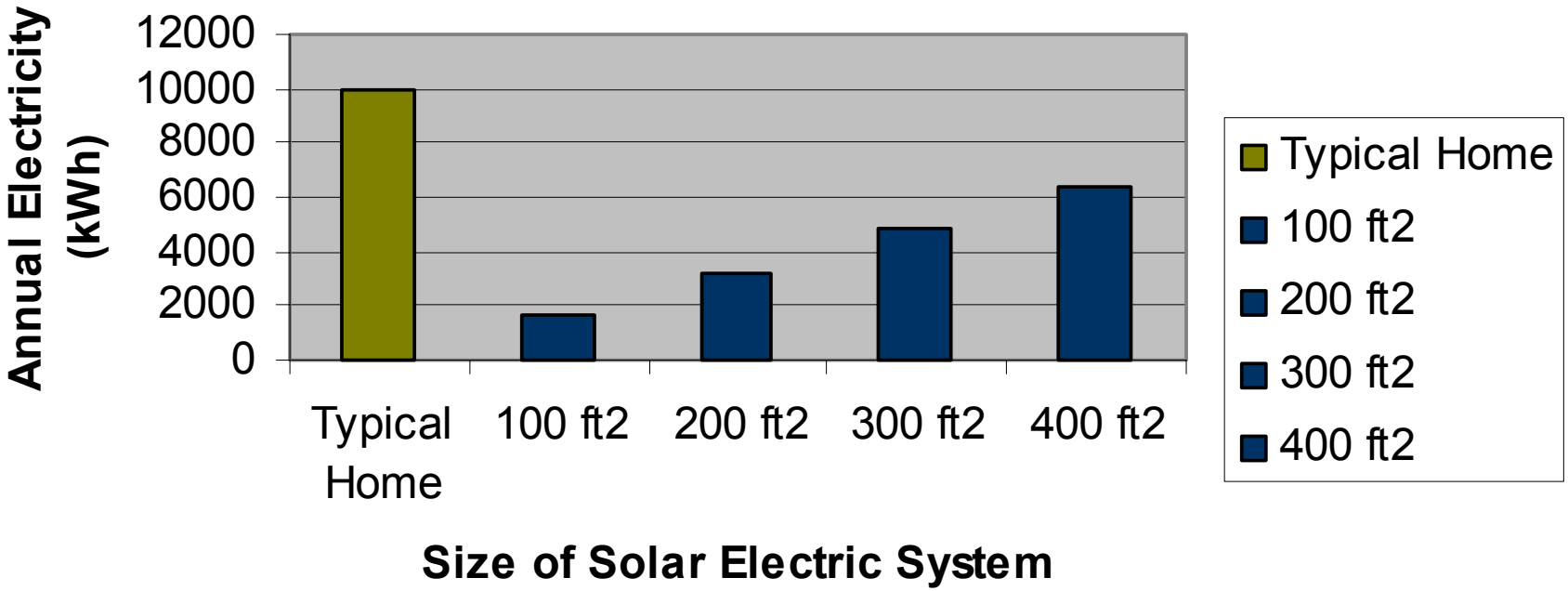
Systems in Texas

- Solar Homes

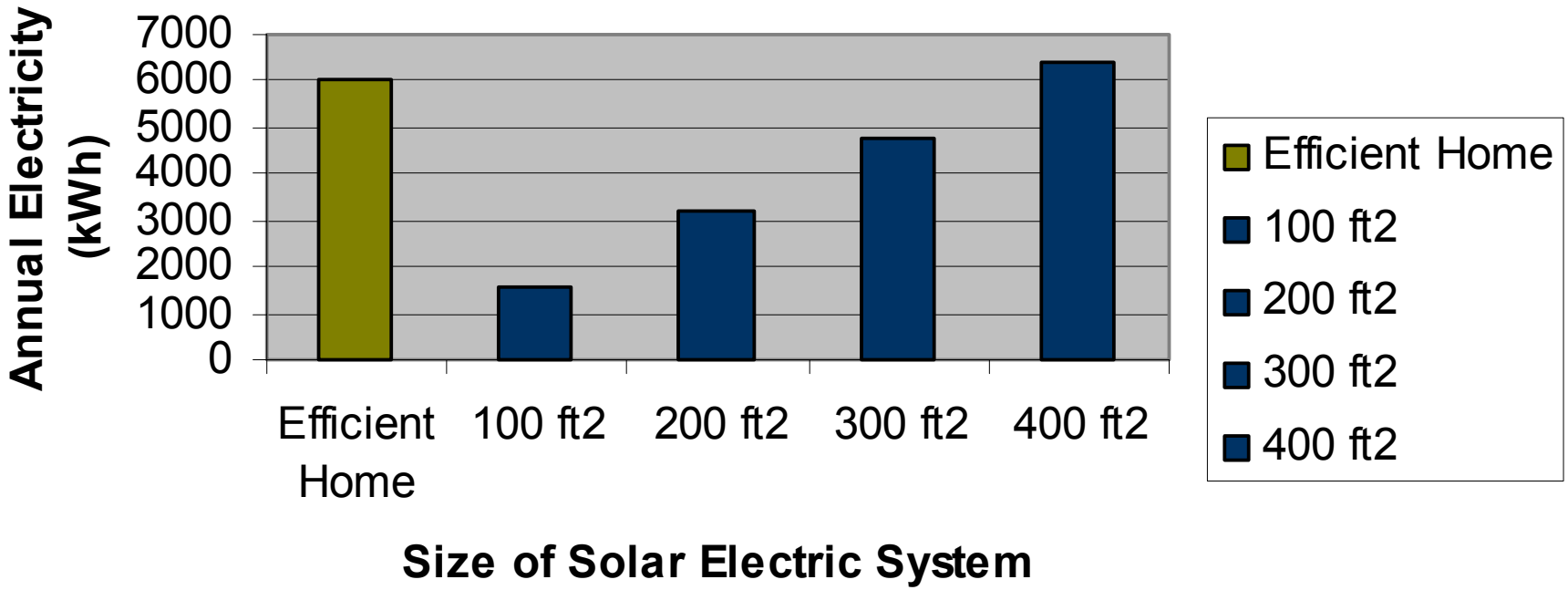
Solar Home – connected to the Electric Utility – AC Systems



Energy From Solar Electric System compared to consumption in a typical Texas home



Energy From Solar Electric System compared to consumption in Efficient Home



Other Systems in Texas

- AEP Solar Schools
- Commercial Buildings
- Sun Power Electric/Green Power

Watts On Schools

What is Watts On Schools?

- 19 Schools Equipped with Solar Energy Generating Stations
- Educational and Public Service Program for Teachers, Students, and the Public
- Research and Development on Solar Energy
- Sponsored by American Electric Power (AEP)
  - AEP-West Texas Utilities Company
  - AEP-Central Power and Light Company
  - AEP-Southwestern Electric Power Company

Solar Energy Systems

- Photovoltaic technology

- Each rated at 4 Kilowatts (kW)
- Each system has 16 PV modules, each about 4 by 6 feet
- Roof- or ground-mounted at the school
- Produces enough electricity to power a small home (or lighting and computers in several classrooms)

Participating Schools

www.wattsonschools.com

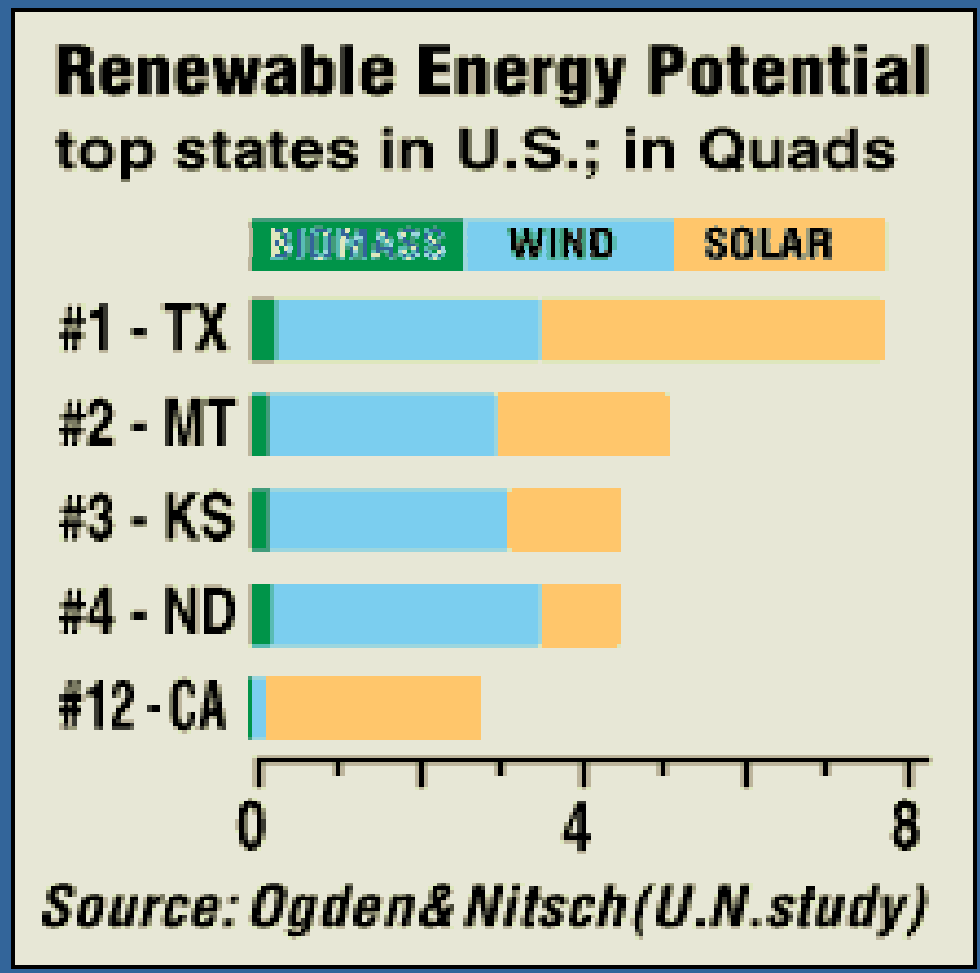
- Primary point of communication and information
- Graphs
- Weather conditions
- Historical data
- Educational activities
- Local information
- Interactive energy calculator
- Links to energy education resources
- Lots more

… In Texas and some History

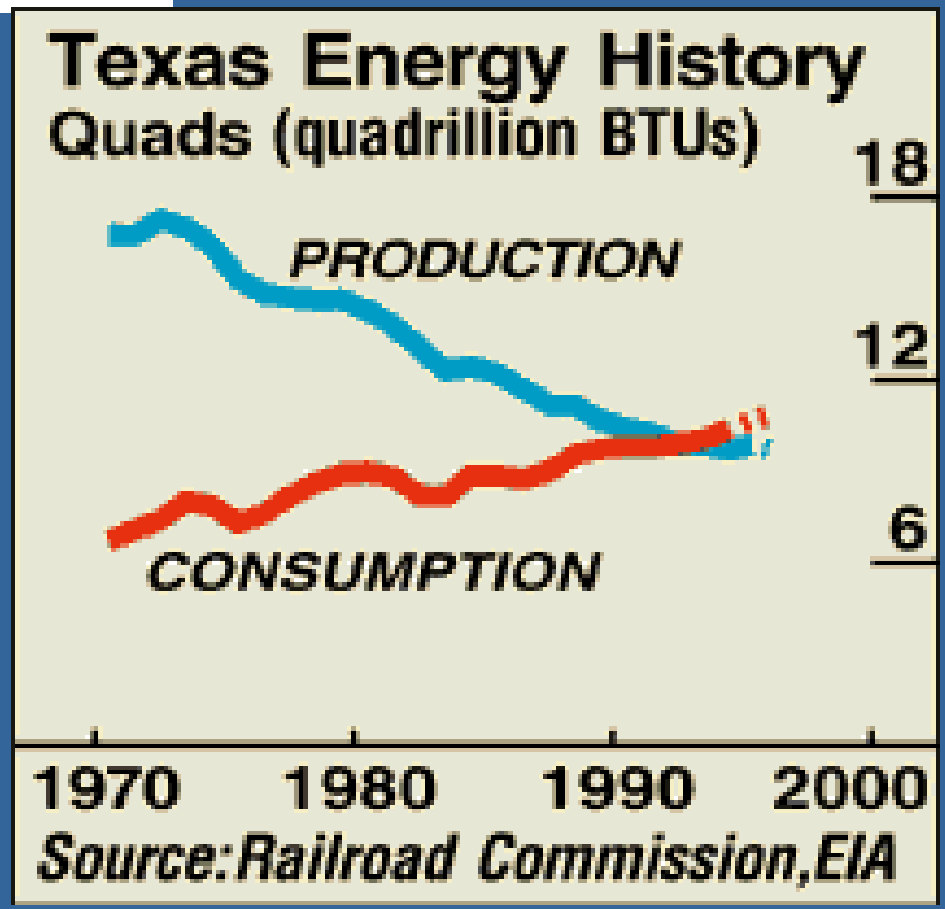
PV in Texas 1980 - 1995

1984	**Net Metering Bill Passed** – Renewables less than 50 kW allowed to net-meter
1986-1995	**City of Austin Utility**: 800 kW of small and large PV and solar water heaters.
	CSW: 225 kW at West Texas Solar Park
	TU: 100 kW concentrator at Energy Park – Dallas and small wind
	HL&P: Several off-grid and small PV

SEDC Study in 1995
Texas Has Best Renewable Potential



Texas became a net importer of energy in mid 1990's



Utility Customer Surveys 1995-1996

- Results indicated - Customers want more efficiency and renewables
- Customers want the utilities to take the lead
- Universal around the state from utility to utility
- Austin 57 % would pay more

Texas PV 1996 -2002

- More market-based renewable programs and Green Power offerings:
  - Austin Energy – Solar Explorer and Green Choice
  - Green Mountain Energy/NUON have installed 3 large-scale systems
  - Residential and Commercial systems throughout the state
  - PV on Schools – AEP and State Program
  - Not much growth in Solar Water, or other technologies.

RENEWABLE ENERGY
THE INFINITE POWER OF TEXAS

Texas Renewable Energy Education Campaign

Senate Bill 7 – Utility Deregulation

- Renewable Mandate
  - 2000 MW of New Renewable Capacity by year 2009
  - Final rules based on Energy
  - Retail Electric Providers must purchase Renewable Energy Credits (RE
  - Penalties for not purchasing
  - Most are purchasing RECs from large Wind
  - Program began in January 2002
  - Large Wind – fantastic growth, close to 1,000 MW
  - Not much small renewable growth

Net Metering?

- Net Metering may not be maintained in its present state if PURPA goes away.
- PUC staff waiting for ruling on a petition from the renewable industr
- PUC may start a process to review Net Metering

Energy Efficiency Rule

- Small renewables eligible for efficiency rebates
- Rebates are based on “deemed” energy and demand savings
- Rebates are paid by local utilities
- First come, first serve basis

Texas -Distributed Generation Rule

Interconnection Rules and Specifications - SR 25.211 + 25.212

Costs for interconnect studies

Pre-certification of standard systems

Rules need some adjusting

Design Assistance and other Resources:

- Texas Renewable Energy Industries Association: www.treia.org
- Texas Solar Energy Society: www.txses.org
- Texas Renewable Education Campaign www.infinitepower.org

- State Energy Conservation Office: Pam Groce 512-463-1889

More Resources

- National Renewable Energy Lab www.nrel.gov
- Sandia National Laboratories (505) 844-7717 - www.sandia.gov/pv